GEMAC
Sensorik. Messtechnik. ASIC-Design.

User Manual

Inclination Sensors with CANopen Interface

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Revision History

Date	Revision	Changes
2010-09-14	0	preliminary
2011-07-01	1	first version
2012-05-31	2	sensor with metal housing added, critical damped digital filter added

Note:

To use the inclination sensor, and for proper understanding of this manual, general knowledge of the field bus systems CAN and CANopen is required.

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Term and Abbreviation Definition

Baud rate	Speed of data transfer (1 Baud = 1 Bit/s)
BOOL	Data type BOOLEAN (8 Bit, 0 = FALSE, 1 = TRUE)
CAN	Controller Area Network
CANopen	Standardized application layer for CAN devices
CiA	CAN in Automation e.V.
CiA DS	CiA Draft Standard (specification published by CiA)
CiA DS-301	Specification of the CANopen application layer and the communication parameters in the OD
CiA DP	CiA Device Profile (device profile published by CiA)
CiA DR	CiA Draft Recommendation (recommended implementation published by CiA)
CiA DR-303-3	Recommended implementation for display of CANopen-device states and errors by LED(s)
CiA DSP	Draft Standard Proposal (specification draft published by CiA)
CiA DSP-410	Specification draft of the device profile 410 for inclination sensors
Client	CANopen station which claims the service of a server
COB	CANopen Communication Object
COB-ID	CAN-Identifier of a COB
DOMAIN	Data type DOMAIN (arbitrary large block of data, e.g. program code)
EDS	Electronic Data Sheet (of a CANopen device)
EMCY	Emergency Object (Object that informs of errors)
xxxxh/xxh	Index/Subindex, position of an OD parameter
Heartbeat	Surveillance mechanism for CANopen stations
ID	Identifier of a CAN message
INT8	Data type INTEGER8 (8 Bit, complement on two, -128...127)
INT16	Data type INTEGER16 (16 Bit, two's complement, -32768...32767)
longitudinal/ lateral	Axis assignment (X/Y-axis)
LSS	Layer Setting Service
NMT	Network Management Object (Object to set and check CANopen device states)
Node-ID	Node number of a CANopen device (1...127)
Node- / Lifeguarding	Surveillance mechanism for CANopen stations
Operational	CANopen device state (SDO, PDO, EMCY, NMT possible)
OD	Object dictionary (virtual directory with device parameters, addressed by index and subindex)
PDO	Process Data Object (Object for transfer of process data without protocol offset)
PDO Mapping	Sequence in which process data is arranged in a PDO
Pre-Operational	CANopen device state (SDO, EMCY, NMT possible)
Pre-defined Connection Set	In CiA DS-301 defined concept how COB IDs of the communication objects have to be calculated in dependence of the Node ID
ro	Read only, access right „read only“ of an object in the object dictionary
RTR	Remote Transmit Request, Bit which causes the receiver to send data
rw	Write and read, access right „write and read“ of an object in the object dictionary
SDO	Service Data Object (object for access to the object dictionary)
Server	CANopen station which offers a service for one/several client(s)
Stopped	CANopen device state (only NMT possible)
UNS8	Data type UNSIGNED8 (8 Bit, without sign, 0...255)
UNS16	Data type UNSIGNED16 (16 Bit, without sign, 0...65535)
UNS32	Data type UNSIGNED32 (32 Bit, without sign, 0...4294967296)
VSTR	Data type VISIBLE STRING (ASCII-string inclusive end identifier 0h)
wo	write only, access right „write only“ of an object in the object dictionary

1 Overview

1.1 Characteristics

- 1-dimensional inclination sensors with measurement range: 360° (±180°)
- 2-dimensional inclination sensors with measurement range: ±90° (X/Y)
- High sampling rate and bandwidth
- High resolution (0.01°) and accuracy (0.05°)
- Compensated temperature coefficient for metal housing
  (10x improved temperature coefficient to plastic housing)
- Compensated cross sensitivity
- Programmable vibration suppression
- Comfortable CANopen interface
  - Meets the CiA DS-301, device profile CiA DSP-410
  - Baud rates from 10 kBit/s to 1 MBit/s
  - Automatic baud rate detection
  - Setting Node ID and baud rate via LSS service
- Functions:
  - One TPDO dynamically mappable (RTR, cyclic, event-controlled, synchronized)
  - SYNC Consumer (synchronized transmission of the TPDO after receiving a SYNC message)
  - EMCY Producer
  - Failure monitoring via Heartbeat or Nodeguarding / Lifeguarding
- Metal housing with stainless steel base plate or UV resistant, impact strength plastic housing
- Suitable for industrial use:
  - Temperature range plastic housing: -40 °C to +80 °C
  - Degree of protection: IP65/67

The inclination sensor IS1D 00 P21 is suitable to measure the inclination in the measurement range of 360°. The 2-dimensional inclination sensor IS2D 90 P21 is suitable to measure the inclination in 2 dimensions (X/Y) in the measurement range of 90°. To ensure a high accuracy, the sensors are calibrated at the factory.

The compact and robust design makes the sensor a suitable angle measurement device in rough surroundings for different applications in industry and automotive technology. A simple setting of all parameters which are stored in the internal permanent memory is possible via CAN bus interface.

1.2 Applications

- Solar thermal and photo-voltaic systems
- Agricultural and forestry machinery
- Construction machinery
- Crane and hoisting technology

2 Technical Data

General Parameters[1]	
Measurement range	360°, ±90°
Resolution	0.01°
Accuracy (Type: IS1D 00 P21)	Range typical maximum 0...360° ±0.04° ±0.10°
Accuracy (Type: IS2D 90 P21)	Range typical maximum up to ±60° ±0.02° ±0.05° up to ±70° ±0.04° ±0.10° up to ±80° ±0.08° ±0.20° up to ±85° ±0.16° ±0.40°
Cross Sensitivity*** (compensated)	typ. ±0.10 %, max. ±0.50 %
Temperature coefficient (zero point)	Metal housing: typ. ±0,0008 °/K (typ. < ±0.10° over range -40 °C … +80 °C) Plastic housing: typ. ±0,0080 °/K
Sampling rate	80 Hz
Cut-off frequency	typ. 20 Hz, 2nd order (without digital filter) / 0.1 ... 25 Hz, 8th order (with digital filter)
Operating temperature	-40 °C to +80 °C
Characteristics	
Data rates	10 k, 20 k, 50 k, 62.5 k, 100 k, 125 k, 250 k, 500 k, 800 k Bit/s, 1 MBit/,s autom detection
Functions	Angle request, cyclical and synchronized outputs, two programmable digital filter (low-pass, 8th order), configuration via object dictionary
Electrical Parameters	
Supply voltage	8 to 48 VDC
Current consumption	Metal housing: <200 mA @ 24 V (PPeak ≤4,8 W) Plastic housing: <33 mA @ 24 V
Mechanical Parameters	
Connector CAN	2x sensor connector 5-pole M12 (loop through connector)
Degree of protection	IP65/67
Dimensions / Weight	Metal housing: 82 mm x 82 mm x 25 mm / ca. 310 g Plastic housing: 66 mm x 90 mm x 36 mm / ca. 215 g
CANopen conformity, Certificate# CiA201108-301V402/20-0143	
CiA DS-301, v4.2.0	Application layer and communication profile
CiA DS-410	Device profile for inclinometer
CiA DSP-305	Layer setting service (LSS) and protocols
CiA DR-303-3	Indicator specification (Status-LED)
CiA AN-801	Automatic bit-rate detection
CE conformity to EC Directive 2006/42/EC	
EC Directives	
RL 2004/108/EC	EMC Directive
RL 2006/95/EC	Low Voltage Directive (LVD)
Harmonized standards	
DIN EN 50498:2010	Electromagnetic compatibility (EMC) - Product family standard for aftermarket electronic equipment in vehicles
EN 60950-1:2006/A1:2010	Information technology equipment. Safety. General requirements
EN ISO 14982:2009	Agricultural and forestry machinery. Electromagnetic compatibility. Test methods and acceptance criteria
DIN EN 13309:2010	Construction machinery - Electromagnetic compatibility of machines with internal power supply

Table 1: Technical Data

1 All indicated angle accuracies are valid after a running time of 10 minutes at 25 °C, Cut-off frequency 0.3 Hz
Absolute calibration accuracy (at 25 °C): ±0.05°

Electromagnetic Compatibility (EMC)			
Transient Emissions			
Radiated disturbance / Radio field strength	Limit curves broadband and narrowband EN ISO 14982 (agricultural and forestry machinery) respectively EN ISO 13309 (construction machinery) 30 ... 1000 MHz (vertical and horizontal)		
Immunity to Radio Frequency Fields (RF fields)			
Strip line according to ISO 11452-5	Limits according to EN ISO 14982 (agricultural and forestry machinery) respectively EN ISO 13309 (construction machinery) 20 ... 400 MHz 200 V/m (1 KHz AM) Performance criteria A		
Anechoic chamber according to ISO 11452-2	Limits according to EN ISO 14982 (agricultural and forestry machinery) respectively EN ISO 13309 (construction machinery) 200 ... 1000 MHz vertical / 400 ... 1000 MHz horizontal 100 V/m (1 KHz AM) Performance criteria A		
Immunity to Conducted Disturbances (on-board power supply 24 VDC)			
Test pulse according to ISO 7637-2:2004	Test pulse 1 -450 V 2a +37 V 2b +20 V 3a -150 V 3b +150 V 4 -12 V 5a +70 V 5b +36 V	Severity level III III III III III III Ri = 1 Ω (10 Ω*) Ri = 0,5 Ω	Performance criteria C B C (B*) A A B A A
Immunity to Electromagnetic Discharge (ESD)			
ESD according to ISO 10605:2008	Limits according to EN ISO 14982 (agricultural and forestry machinery) respectively EN ISO 13309 (construction machinery) discharge combination 330 pF / 330 Ω Contact discharge 8 KV bipolar (metallic parts) Air discharge 15 KV bipolar Performance criteria A		

Table 2: Electromagnetic Compatibility (EMC)

* Metal housing

Certificate # **CiA201108-301V402/20-0143**

Vendor ID **00 00 01 59**

Manufacturer Gemac mbH

Device IS2D 90 P21

Product code: Object 1018h/02h	0000 5A72h	Revision number: Object 1018h/03h	0000 001Eh
Hardware version: Object 1009h	-	Software version: Object 100Ah	V03.39

EDS PR-23154-xx.eds

File version:	1	File revision:	0
EDS version:	4.0.2		

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Figure 1: CiA CANopen Conformance Test Certificate

3 Mounting

3.1 Position of Drilling Holes

The four drilling holes to mount the sensor (Figure 2 and Figure 3) are situated in the base plate of the inclination sensor.

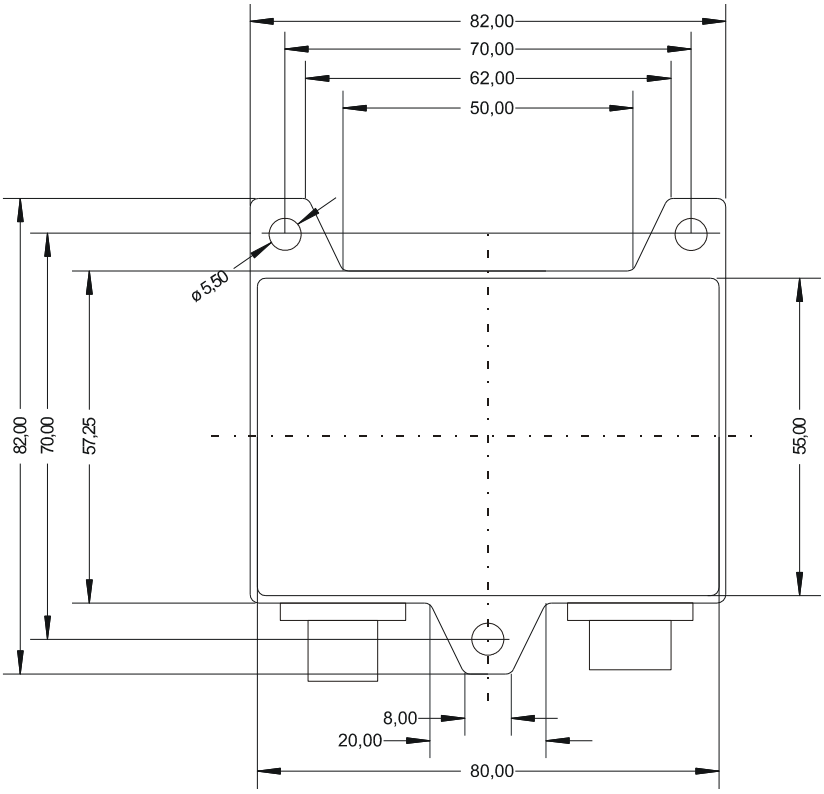


Figure 2: Dimensioned Sketch of metal housing

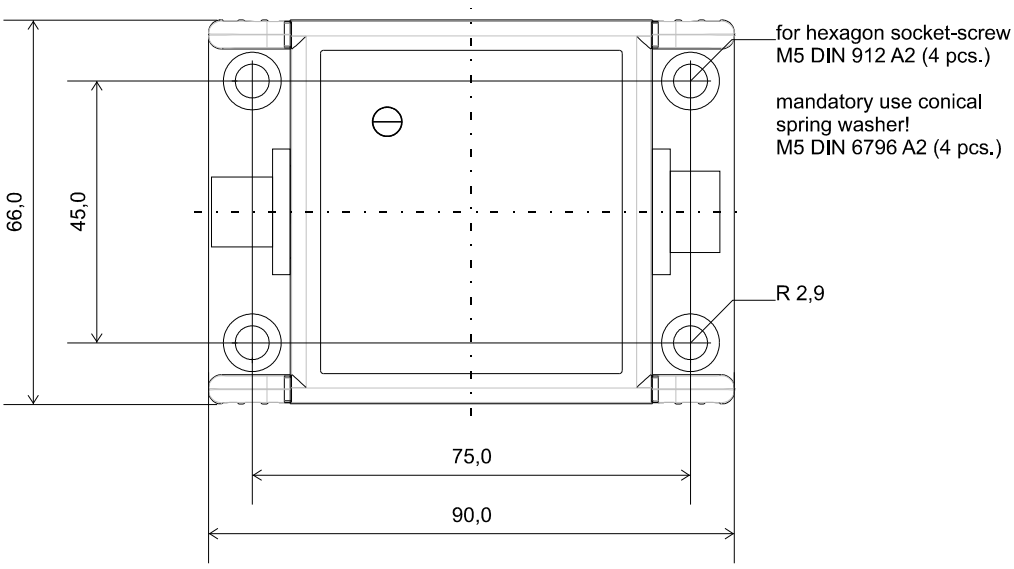


Figure 3: Dimensioned Sketch of plastic housing

3.2 Definition of the Axes

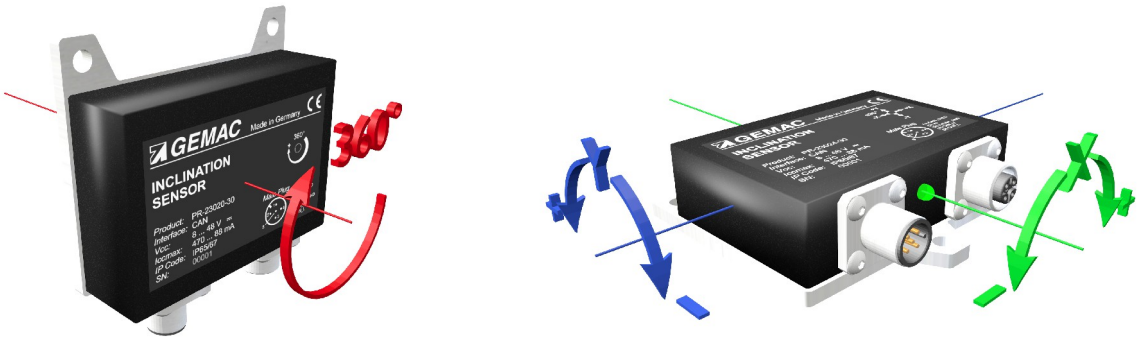


Figure 4: Definition of the Axes metal housing (factory default settings)

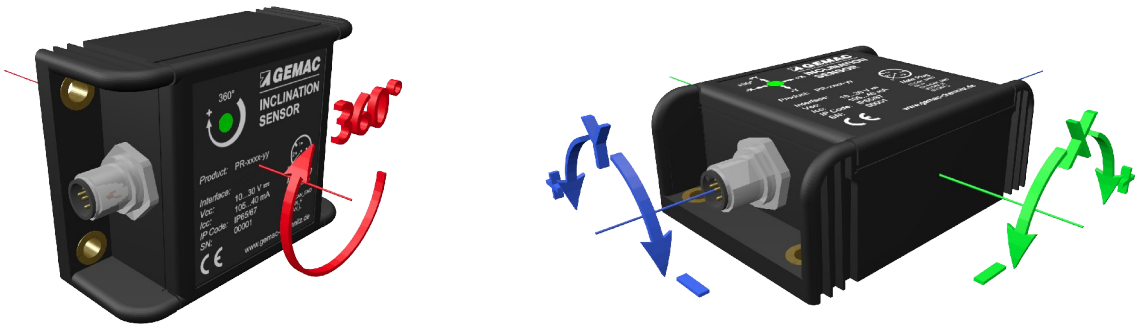


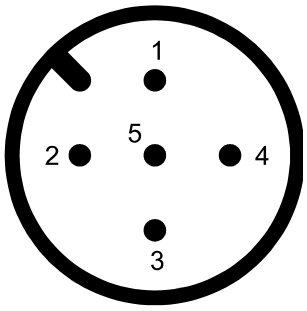
Figure 5: Definition of the Axes plastic housing (factory default settings)

4 Connection

4.1 Connector Pin Out

The inclination sensors IS1D 00 P21 and IS2D 90 P21 are equipped with a common 5-pole round plug M12 (A-coded). The pin allocation fulfills CiA DR-303-1 (Figure 6).

Pin	Signal	Allocation
1	CAN_SHLD	Shield
2	CAN_V+	Supply voltage (+24 V)
3	CAN_GND	GND / 0 V / V-
4	CAN_H	CAN_H bus line
5	CAN_L	CAN_L bus line



(View from the outside)

Figure 6: Connector Pin Out CAN Bus

4.2 Bus-Termination Resistor

The inclination sensors contain no internal termination resistor.

5 Function Description

5.1 Overview of Function

The inclination sensors IS2D xx P06 / P07 contain a standardized CANopen interface according to CiA DS-301 and a device profile according to CiA DSP-410. All measured values and parameters are accessible through the object dictionary (OD). The individual configuration can be saved in the internal permanent memory (EEPROM). The following CANopen functions are available:

- One transmission data object (TPDO1) dynamically mappable in four possible operating modes:
  - Individual request via remote transmit request message frame (RTR)
  - Cyclic transmission at defined intervals
  - Event-controlled transmission on inclination change
  - Synchronous transmission after receiving a SYNC message frame
- One Service Data Object (Default SDO)
- Error messages by Emergency Object (EMCY) with support of the
  - General Error Register
  - Manufacturer specific status register (Manufacturer Status)
  - List of errors (Pre-defined Error Field)
- Heartbeat and Nodeguarding / Lifeguarding monitoring mechanisms
- Store and load function of all parameters (Store and Load Parameter Field)
- Condition and error information by two-colored LED (according to CiA DR-303-3)

Further manufacturer and profile specific characteristics exist in addition to the CiA DS-301 functionality:

- Configurable cut-off frequency (digital filter)
- Configuration of the minimum angle change for TPDO1 transmit event
- Direction switch of the inclination value
- Configurable zero point of the inclination value
- Setting of the Node-ID as well as the baud rate via LSS service according to CiA DSP-305
- Automatic baud rate detection according to CiA AN-801

6 CANopen Interface

6.1 CANopen Structure

CANopen is a CAN-based open protocol standard in automation and was standardized in association with “CAN in Automation” (CiA). Like virtually all field buses CANopen is based also on the ISO/OSI 7-layer model. The protocol makes use of the CAN bus as a transmission medium and defines the elements for network management, the use of the CAN identifier (message address), the temporal behavior on the bus, the type of data transfer and application profiles. This is to ensure that CANopen devices from different manufacturers can be combined.

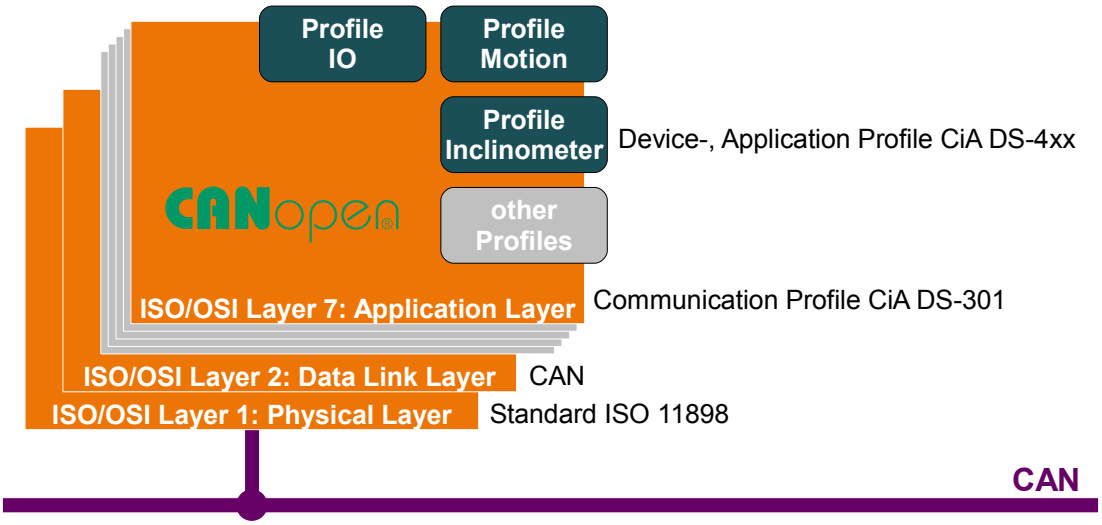


Figure 7: CANopen Structure

CANopen describes the ISO / OSI layer 7 (application layer) as a communication profile that was specified in the CiA standard CiA DS-301. The standard defines the method of communication for all devices consistently. In addition, more device and application profiles for specific classes of devices and applications in the CiA standard DS-4xx are defined.

6.2 CANopen Device Model

The exchange of data between CANopen devices is realized via data objects. The CANopen communication profile thus provides for the following types of objects. The process data objects (PDO) are high-priority messages used for the exchange of process data. Access to the object dictionary of a device is done via the service data objects (SDOs). Network management objects are used to control the state machine of the CANopen device and to monitor the nodes. Furthermore, there are special objects for error messages (Emergency), Synchronization (SYNC) and time stamp. Every CANopen device has a CANopen object dictionary, in which the parameters for all CANopen objects are registered.

6.3 COB-IDs

The CAN identifier of the communication objects is determined according to the Pre-defined connection set at each reset (communication, application and hardware reset), depending on the selected Node-ID. Table 3 shows the calculation base with the default values (Node-ID = 10).

Communication object (COB)	Calculation of the COB-ID	Default value (Node-ID = 10)
NMT	0h	0h
SYNC	80h	80h
EMCY	80h + Node-ID	8Ah
TPDO1	180h + Node-ID	18Ah
Default SDO (Client > Server)	600h + Node-ID	60Ah
Default SDO (Server > Client)	580h + Node-ID	58Ah
Heartbeat	700h + Node-ID	70Ah

Table 3: Calculation of the COB-IDs for Pre-defined Connection Set

6.4 Network Management: NMT

Figure 8 shows the NMT state machine of a CANopen device. After **Initialization** the device automatically goes into the state **Pre-Operational**. The device sends a **Boot-Up Message**. In this state it can be configured via the object dictionary. The service data objects (SDO) are already active. The process data objects, however, are still locked.

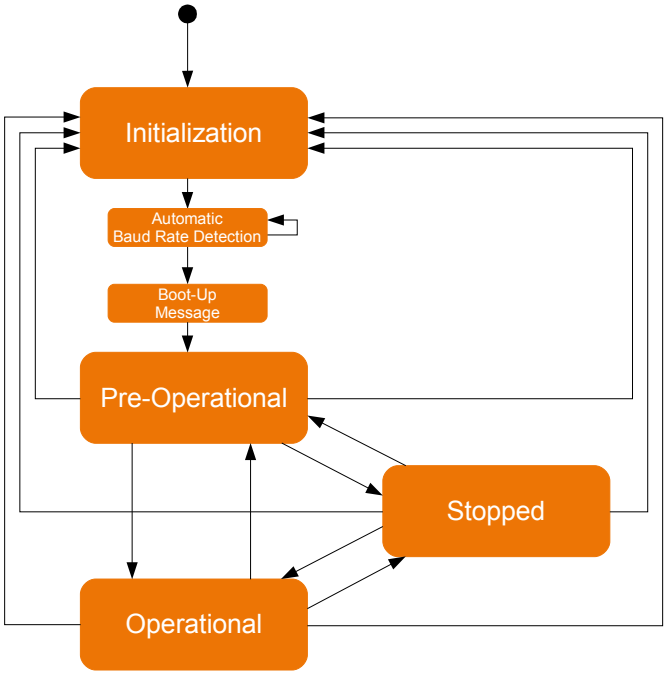


Figure 8: NMT State diagram

By sending the CAN message "Start Remote Node" the unit will go into the state **Operational**. Now the process data objects are active. In **Stopped** state, no communication with the exception of Nodeguarding and Heartbeat is possible.

6.5 Process Data: PDO (TPDO1)

Each inclination sensor has exactly one transmit process data object (TPDO). The TPDO contains the current values of inclination (axial or longitudinal and lateral). The PDO mapping of the measured values is dynamically adjusted. The default mapping is shown inTable 4/5.

Data part of the CAN Frame of the TPDO1							
Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
Inclination value axial (OV: 6010h)		unused					

Table 4: TPDO1 Default mapping Type: IS1D 00 P21

Data part of the CAN Frame of the TPDO1							
Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
Inclination value longitudinal (X-Axis, OV: 6010h)		Inclination value lateral (Y-Axis, OV: 6020h)		unused			

Table 5: TPDO1 Default mapping Type: IS2D 90 P21

6.5.1 PDO Communication Types

6.5.1.1 Individual Request (Polling)

The TPDO1 can be requested at any time by transmitting a remote-transmit request message frame.

6.5.1.2 Cyclic Transmission

The cyclic transmission of the TPDO1 is activated if the entry 1800h/05h (interval time in milliseconds) contains a value greater than 0. Furthermore, the entry 1800h/02h (transmission type) must contain the value 254 (asynchronous, manufacturer-specific). In this case, the inclination sensor will transmit the TPDO1 cyclically at the set period interval when in the OPERATIONAL state.

6.5.1.3 Synchronous Transmission

The synchronous transmission is used to get inclination values from more then one sensor at the same time. Therefore CANopen provides a SYNC object - a CAN message without user data - transmitted with high priority on the bus. This SYNC object is transmitted from a bus node (usually the master) cyclically at fixed intervals. All inclination sensors read their current value after every n^{th} reception of the SYNC object and then transmit the TPDO1 directly as soon as the bus permits. For this the entry 1800h/02h (Transfer Type) must contain the value n = 1...240.

6.5.1.4 Event-controlled transmission on inclination change (manufacturer specific)

The bus load from PDOs can be reduced if the TPDO1 is only transmitted when an appropriate angle change has occurred. This function can only be configured in the manufacturer-specific part of the object directory under index 3001h. To this end, the entry 1800h/02h (transmission type) must contain the value 254 (asynchronous, manufacturer-specific).

6.6 Service Data: SDO

The parameters, listed in the object dictionary, are read and written through Service Data Objects (SDOs). As shown in Table 6, every object can directly be addressed over a 16-bit index. In addition, each index has an 8-bit subindex that allows an additional choice within an index. The 8 bytes of the SDOs are placed in the data area of the CAN message.

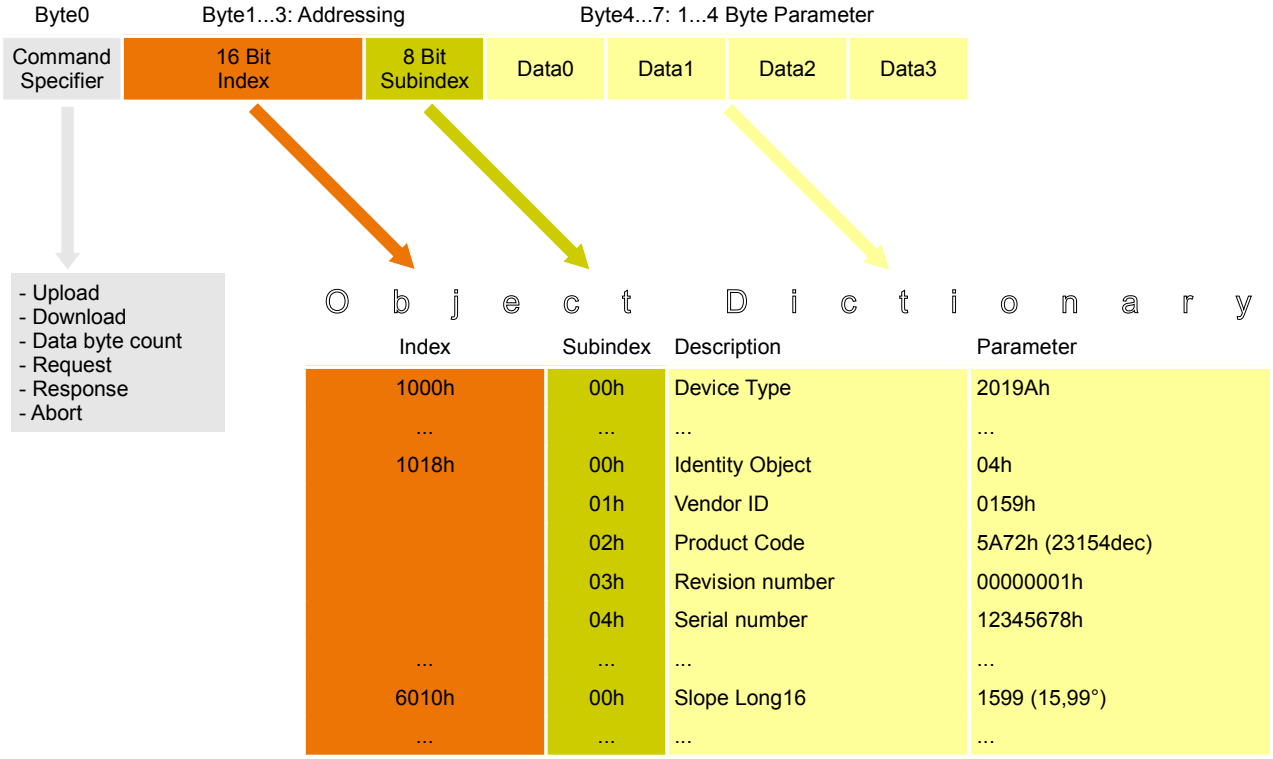


Figure 9: SDO Protocol – Access to Object Dictionary

6.7 Object Dictionary

The object directory contains all data objects that are accessible from the outside and affect the behavior of communication, application and status machines. It is divided into three parts:

- Communication specific Part (Index: 0x1000 – 0x1FFF)
- Manufacturer specific Part (Index: 0x2000 – 0x5FFF)
- Profile specific Part (Index: 0x6000 – 0x9FFF)

All parameters in the object dictionary can be read and written using the standard SDO via index and subindex.

The following sections describe all the parameters in the object dictionary of the inclination sensor with index, subindex, data type, access rights and default (factory setting). The column "Save" indicates whether a parameter in the internal volatile memory ("save" signature in OD-Write Index 1010h/01h) can be saved.

6.7.1 Communication Parameters (according to CiA DS-301)

Index	Sub-Index	Parameter		Data Type	Access	Default Value	Save
1000h	0	Device Type (Device profile 410), Type IS1D 00 P21 / IS2D 90 P21		UNS32	const	1019Ah/2019Ah	
1001h	0	Error Register		UNS8	ro	0	
1002h	0	Manufacturer Status Register		UNS32	ro	0	
1003h	Pre-defined Error Field						
	0	Number of Errors entries		UNS32	rw	0	
	1..5	Error Code (oldest error on highest index)		UNS32	ro	0	
1005h	0	COB-ID Sync Message		UNS32	rw	80h	
1008h	0	Manufacturer Device Name		VSTR	const	{dep. on type}	
100Ah	0	Manufacturer Software Version („Vxx.yy“)		VSTR	const	{dep. on type}	
100Ch	0	Guard Time (Multiple of 1 ms)		UNS16	rw	0	x
100Dh	0	Life Time Factor		UNS8	rw	0	x
1010h	Store Parameters (Signature: 's','a','v','e' - 65766173h at SubIndex 1...4)						
	0	Largest supported SubIndex		UNS32	ro	4	
	1	Save all Parameters	(OV: 0x1000-0x9FFF)	UNS32	rw	1	
	2	Save Communication Parameters	(OV: 0x1000-0x1FFF)	UNS32	rw	1	
	3	Save Application Parameters	(OV: 0x6000-0x9FFF)	UNS32	rw	1	
	4	Save Manufacturer Parameters	(OV: 0x2000-0x5FFF)	UNS32	rw	1	
1011h	Restore Default Parameters (Signature: 'l','o','a','d' - 64616F6Ch at SubIndex 1...4)						
	0	Largest supported SubIndex		UNS32	ro	4	
	1	Restore all Default Parameters	(OV: 0x1000-0x9FFF)	UNS32	rw	1	
	2	Restore Communication Default Parameters	(OV: 0x1000-0x1FFF)	UNS32	rw	1	
	3	Restore Application Default Parameters	(OV: 0x6000-0x9FFF)	UNS32	rw	1	
	4	Restore Manufacturer Default Parameters	(OV: 0x2000-0x5FFF)	UNS32	rw	1	
1014h	0	COB-ID Emergency Message		UNS32	ro	80h + Node-ID	
1015h	0	Inhibit Time Emergency (multiple of 100 µs)		UNS16	rw	0	x
1017h	0	Producer Heartbeat Time (multiple of 1 ms, 0 inactive)		UNS16	rw	0	x
1018h	Identity Object						
	0	Largest supported SubIndex		UNS8	ro	4	
	1	Vendor-ID (Manufacturer ID: GEMAC mbH)		UNS32	ro	159h	
	2	Product Code		UNS32	ro	{dep. on type}	
	3	Revision number		UNS32	ro	{dep. on type}	
	4	Serial number		UNS32	ro	{dep. on type}	
1200h	Server SDO1 Parameter						
	0	Largest supported SubIndex		UNS8	ro	2	
	1	COB-ID Client > Server		UNS32	ro	600h + Node-ID	
	2	COB-ID Server > Client		UNS32	ro	580h + Node-ID	
1800h	Transmit PDO1 Communication Parameter						
	0	Largest supported SubIndex		UNS8	ro	5	
	1	COB-ID		UNS32	ro	180h + Node-ID	
	2	Transmission Type (synchronous / asynchronous manufacturer specific)		UNS8	rw	1	x
	3	Inhibit Time between two TPDO Messages (multiple of 100 µs)		UNS16	rw	0	x
	4	Compatibility Entry		UNS8	rw	0	x

	5	Event Timer (Multiple of 1 ms, 0 inactive)	UNS16	rw	0	x
1A00h	Transmit PDO1 Mapping Parameter					
	0	Largest supported SubIndex	UNS8	ro	{dep. on type}	
	1	Mapping Entry 1, both types: IS1D 00 P21 / IS2D 90 P21	UNS8	rw	0x60100010	x
	2	Mapping Entry 2, Type: IS1D 00 P21 / IS2D 90 P21	UNS8	rw	0 / 0x60200010	x
	3	Mapping Entry 3	UNS8	rw	0	x
	4	Mapping Entry 4	UNS8	rw	0	x
	5	Mapping Entry 5	UNS8	rw	0	x
	6	Mapping Entry 6	UNS8	rw	0	x
	7	Mapping Entry 7	UNS8	rw	0	x
	8	Mapping Entry 8	UNS8	rw	0	x
1F50h	Download Program Data					
	0	Largest supported SubIndex	DOMAIN	ro	3	
	1	Area Firmware	DOMAIN	wo	-	
	2	Area Configuration 1, (Access only to manufacturers)	DOMAIN	wo	-	
	3	Area Configuration 2, (Access only to manufacturers)	DOMAIN	wo	-	
1F50h	Download Program Control					
	0	Largest supported SubIndex	UNS8	ro	3	
	1	Area Firmware	UNS8	rw	1	
	2	Area Configuration 1, (Access only to manufacturers)	UNS8	rw	1	
	3	Area Configuration 2, (Access only to manufacturers)	UNS8	rw	1	

Table 6: Communication Parameters in the Object Dictionary

6.7.1.1 Error Register (1001h)

The error register displays the general error state of the device. Each bit stands for an error group. If one bit is set (= 1), at least one error of that specific group occurs. The content of this register is transmitted in each EMCY object. The following error groups can occur:

Error Register (1001h)							
Bit7	**Bit6**	**Bit5**	**Bit4**	**Bit3**	**Bit2**	**Bit1**	**Bit0**
Manufacturer Specific Error	Accuracy Warning	Profile Specific Error	Communication Error	Unused			At least one active fault

Table 7: Error Register (1001h)

If the device is in error state (at least one active error) this is shown by the set Bit0 (= 1). In the event of a communication error (overflow of the transmit / receive buffers, guarding errors or CAN controller in the passive mode / Bus-Off) the Bit4 is set. A device profile specific error (sensor error) is shown by Bit5. The Bit7 indicates a vendor-specific error (EEPROM error). The bit “Accuracy Warning” is reset only, when the constant temperature for temperature compensation is reached. Only in this case the accuracy values from the technical specification are valid.

6.7.1.2 Manufacturer Status Register (1002h)

This Register shows the recent state of all detectable errors. Here each bit represents a specific error. If a bit is set (= 1), this error is active at that moment. The low ordered 16 bits of this register (Bit15...Bit0) are transmitted in the first two bytes of the manufacturer specific part of each EMCY object and are also re-

gistered in the additional information field (Bit31-Bit16) of the Pre-defined Error Field 1003h. The definitions of the individual bits in the bit fields "Device Error" and "Communication Error" are shown in Table 18.

Manufacturer Status Register (1002h)		
Bit31...Bit16	**Bit15...Bit8**	**Bit7...Bit0**
Unused	Bit field Communication Error	Bit field Device Error

Table 8: Manufacturer Status Register (1002h)

6.7.1.3 Pre-defined Error Field (1003h)

Each inclination sensor has an error list holding the last five errors. The list 1003h/00h contains the number of error entries in the error field. The other subindices contain all occurred error states in chronological order. The last occurred error is always located at SubIndex 01h. The oldest error can be found in the largest available SubIndex (value of 1003h/00h) and will be the first to be deleted from the list with occurrence of more than five errors. If a new error occurs a new error entry is added in 1003h and is also notified by an EMCY object. An error entry is structured as follows:

Error Entry in Pre-defined Error Field (1003h)		
Additional Information Field (Bit31...Bit16)		Error Code (Bit15...Bit0)
Bit15...Bit0 of the manufacturer status register 1002h (at the moment of error occurrence)		0x0000 Error reset or no error present 0x5010 Sensor Error / Sensor Error X 0x5020 Sensor Error Y 0x8110 Overflow of the transmit / receive buffers 0x8120 CAN Warning Limit reached 0x8130 Node Guard Event 0x8140 Recovered from Bus-Off
Bit field Communication error	Bit field Device Error	

Table 9: Error Entry in Pre-defined Error Field (1003h)

The error list can be reset completely by writing 0 to entry 1003h/00h.

6.7.1.4 Saving (1010h) and Loading (1011h) of Parameters

If parameters are changed in the object dictionary those changes will take effect immediately. To ensure the changed parameters are still active after Reset they have to be saved in the internal EEPROM. By writing the signature „save“ (65766173h) to the entry 1010h/01h all the current parameters of the object dictionary will be saved in the internal permanent memory.

The object dictionary can be reset to its default settings by writing the signature „load“ (64616F6Ch) into the entry 1011h/01h. By doing this the factory parameters are written in the permanent memory. After a „Reset Application“ (NMT command) or a hardware reset the changes will take effect (a „Reset Communication“ (NMT command) effects the communication parameters only).

By writing the signature on SubIndex: 02h, 03h or 04h, it is possible to store or load only parts of the object directory.

6.7.1.5 Transmit PDO1 – Transmission Type (1800h)

The entry 1800h/02h can be used to define how the transmission of the PDO is triggered.

Transmit PDO1 - Transmission Type (1800h/02h)	
Transmission Type	**Description**
1...240	Synchronous (cyclic) Transmission after each 1...240 reception of a SYNC message only „Synchronized Transmission“ via SYNC possible
253	Transmission with RTR only
254	Asynchronous, manufacturer-specific „Cyclic Transmission“ and/or „Transmission on Inclination Change“ activated by appropriate configuration

Table 10: Transmit PDO1 - Transmission Type (1800h/02h)

6.7.2 Manufacturer Specific Part

Index	Sub-Index	Parameter	Data type	Access	Default value	Save
2002h	0	Automatic Bus-Off Recovery	BOOL	rw	0	x
3000h	Digital Filter Settings					
	0	Largest supported SubIndex	UNS16	ro	2	
	1	Filter type (0=off, 1=Butterworth, 2=critical damped)	UNS16	rw	2	x
	2	Cut-off frequency digital filter	UNS16	rw	2000	x
3001h	TPDO1 Transmission on Inclination Change, Type IS1D 00 P21					
	0	Largest supported SubIndex	UNS16	ro	2	
	1	Enable/Disable (1/0) transmission on inclination change	UNS16	rw	0	x
	2	Minimum inclination change for axial axis (multiple of °/100)	UNS16	rw	100	x
3001h	TPDO1 Transmission on Inclination Change, Type IS2D 90 P21					
	0	Largest supported SubIndex	UNS16	ro	3	
	1	Enable/Disable (1/0) transmission on inclination change	UNS16	rw	0	x
	2	Minimum inclination change for longitudinal (X) axis (multiple of °/100)	UNS16	rw	100	x
	3	Minimum inclination change for lateral (Y) axis (multiple of °/100)	UNS16	rw	100	x
5555h	Reserved index (access for manufacturer only)					

Table 11: Manufacturer Specific Part of the Object Dictionary

6.7.2.1 Automatic Bus-Off Recovery (2002h)

This property determines the behavior of the inclination sensor when it is in the state Bus-Off. If enabled, the sensor, which is in Bus-Off state may become error-active (no longer Bus-Off) with its error counters both set to zero after having monitored one hundred and twenty-eight (128) occurrences of eleven (11) consecutive recessive bits on the bus.

If disabled, the inclination sensor remains in Bus-Off state.

6.7.2.2 Digital Filter Settings (3000h)

The inclination sensor offers the possibility to suppress the influence of external disturbing vibrations. The internal lowpass digital filters (8th order) are programmable down to 0.1 Hz. The sensor has two digital filters that can be selected according to the application of the sensor.

Filter	Adjustable frequency range	Applications
Butterworth	0,1 Hz ... 25 Hz	Static inclination measurement with high damping to vibration
Critical damped	0,1 Hz ... 8 Hz	Inclination measurement in applications that requires a certain dynamism, without overshoot at angle changes with good damping

Table 12: Filter selection

Through the entry 3000h/02h the filter type will be selected. The cut-off frequency is programmable through the object 3000h/02.

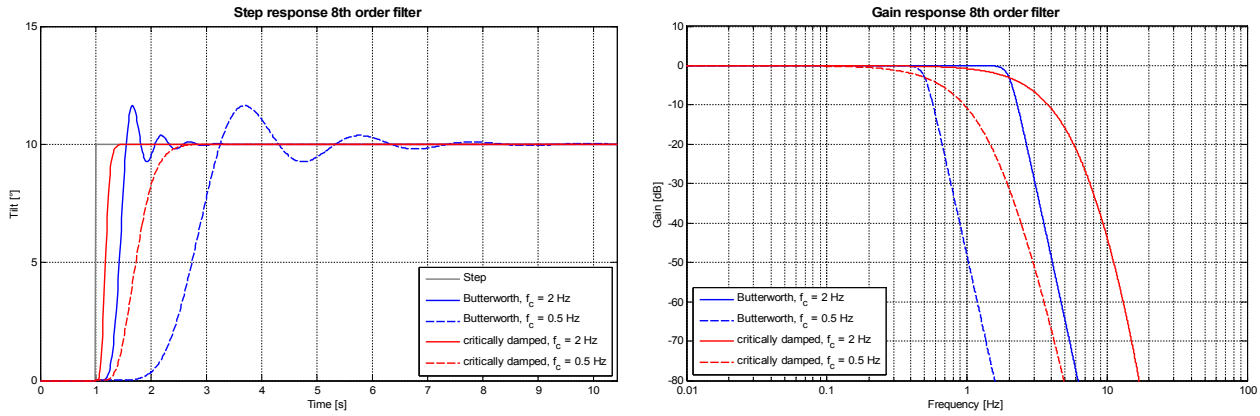


Figure 10: Impulse and amplitude response of the two filters

6.7.2.3 TPDO1 Transmission on Inclination Change (3001h)

Through the entry 3001h/01h the event controlled transmission of the TPDO1 on inclination change can be enabled (= 1) or disabled (= 0). For the activation the transmission type of TPDO1 must be set to “Asynchronous, manufacturer-specific” (1800h/02h = 254).

SubIndices 02h and 03h offer the separated setting of the minimum necessary inclination change for the longitudinal (X) and lateral (Y) axis. These two angle values are mentioned in °/100 (100fold angle value) and can be set freely from 1 = 0.01° to maximum.

If this function is enabled the inclination sensor outputs the TPDO1 object in the state OPERATIONAL in case of inclination changes of the longitudinal and/or the lateral axis greater than set under 3001h/02h and 03h. During operation the angle difference between the recent inclination value and the last one sent by the TPDO1 is permanently calculated and checked. With each crossing to the state OPERATIONAL the inclination sensor posts the recent position by the TPDO1 object, too (only if 3001h/01h = 1).

Remarks:
If small inclination differences are set under 3001h/02h and 03h it is recommended to enable the digital filter (index 3000h) to reduce the influence of vibrations and the frequent output of the TPDO1.

6.7.3 Device Profile Specific Part (according to CiA DS-410)

Index	Sub-Index	Parameter	Data type	Access	Default value	Save
6000h	0	Resolution (multiple of 0,001°)	UNS16	ro	10	
6010h	0	Inclination value longitudinal (X-axis, 100fold angle value in °)	INT16	ro	-	
6011h	0	Operating Parameter longitudinal (Inversion, Zero Point Adjustment)	UNS8	rw	0	x
6012h	0	Preset Value longitudinal (X) Axis	INT16	rw	0	x
6013h	0	Offset Value longitudinal (X) Axis	INT16	rw	0	x
6014h	0	Differential Offset Value longitudinal (X) Axis	INT16	rw	0	x
6020h	0	Inclination value lateral (X-axis, 100fold angle value in °)	INT16	ro	-	
6021h	0	Operating Parameter lateral (Inversion, Zero Point Adjustment)	UNS8	rw	0	x
6022h	0	Preset Value longitudinal (Y) Axis	INT16	rw	0	x
6023h	0	Offset Value longitudinal (Y) Axis	INT16	rw	0	x
6024h	0	Differential Offset Value longitudinal (Y) Axis	INT16	rw	0	x

Table 13: Device Profile Specific Part of the Object Dictionary

6.7.3.1 Resolution (6000h)

The resolution of all inclination sensors are set to 0.01° (default: 10 * 0.001°). All angle values in the object dictionary (6010h, 6012h, 6013h, 6014h and 6020h, 6022h, 6023h, 6024h) are to be interpreted as a multiple of 0.01 °.

Example:
Inclination value = -2370 x 0.01° → -23.70°

6.7.3.2 Inclination values longitudinal and lateral (6010h and 6020h)

The recent inclination values of the inclination axes are accessible by SDO access to the object dictionary (in each device state) as well as by TPDO. If Zero Point Adjustment is enabled via the operating parameters 6011h and 6021h, the inclination value is calculated as follows:

Inclination Value = Physically Measured Inclination Value + Diff. Offset Value + Offset Value

On disabled Zero Point Adjustment:

Inclination Value = Physically Measured Inclination Value

The conversion of the 100fold, signed 16-Bit inclination value (complement on two) is described in chapter 6.7.3.3 .

Example:
Value Range Type IS1D 00 P21: -18000 ... +17999 → -180,00° ... +179,99° = 0 ...359,99°
Value Range Type IS2D 90 P21: -9000 ... +9000 → - 90,00° ... + 90,00°

6.7.3.3 Operating Parameters (6011h and 6021h)

The operating parameters settings of an inclination sensor (6011h and 6021h) allow the changing of the mathematical sign of the inclination value and a Zero Point Adjustment. On Factory Default Settings, these

options are disabled, i.e. the direction of the inclination value (polarity of the axis) corresponds to the one shown on the nameplate of the inclination sensor.

Operating Parameters (6011h and 6021h)							
Bit7	**Bit6**	**Bit5**	**Bit4**	**Bit3**	**Bit2**	**Bit1**	**Bit0**
Unused						Zero Point Adjustment 0 = /inactive 1 = active	Inversion 0 = /inactive 1 = active

Table 14: Operating Parameters (6011h and 6021h)

6.7.3.4 Zero Point Adjustment: Preset Value, Offset Value, Differential Offset Value (60x1/2/3h)

Using the values “Preset Value”, “Offset Value” and “Differential Offset Value” the adjustment of the Zero Point is possible. The Zero Point Adjustment is only active if the Bit1 in the operating parameters (6011h/6021h) is set.

Value	Object	Description
Preset Value	6012h 6022h	Preset Value for Zero Point Adjustment, value range depends on settings in object 6000h
Offset Value	6013h 6023h	Calculated Offset Value when writing to object 6012h or 6021 Calculated Offset Value = Preset Value at tacc – physically measured Inclination Value at tacc – Differential Offset Value tacc: time when accessing object (6012h,6022h)
Differential Offset Value	6014h 6024h	Additional Offset, regardless of object 6012h and 6013h / 6022h and 6023h The value you enter here will be added up directly to the inclination value.

Table 15: Zero Point Adjustment

6.8 Emergency Objects

Each inclination sensor supports EMCY objects which are transmitted in case of sensor and hardware errors. If such an error occurs the OD entries 1001h (Error Register), 1002h (Manufacturer Status Register) and 1003h (Pre-defined Error Field) are updated. After abolishment of an error, the device transmits an emergency message with the Error Reset Code 0x0000. Yet current errors are signaled in Byte2 (Error Register) and Bytes 3,4 in the Manufacturer specific error field. Once the device is error-free, it sends an emergency message which contains only zeros. The current state of the device (Pre-Operational, Operational or Stopped) is not influenced by the error states, except in case of a guarding error.

Emergency messages are sent with high priority on the bus and are always 8 bytes long. The structure of the telegram is presented in Table 16:

Emergency Object							
Byte0	**Byte1**	**Byte2**	**Byte3**	**Byte4**	**Byte5**	**Byte6**	**Byte7**
Emergency Error Code		Error Register (1001h)	Manufacturer Specific Error Field				
			Bit field Communication Error	Bit field Device Error	0x00	0x00	0x00

Table 16: Emergency Object

Emergency Error Codes	
0x0000	Error Reset or no Error (Error Register = 0)
0x5010	Sensor Error / Sensor Error X, Inclination value out of range
0x5020	Sensor Error Y, Inclination value out of range
0x8110	Overflow of the transmit / receive buffers, CAN messages were lost
0x8120	CAN Warning Limit reached
0x8130	Node Guard Event (The loss of the Guarding-Master has been detected)
0x8140	Recovered from Bus-Off

Table 17: Emergency Error Codes

Bit field Device Errors		
0x01	Sensor Error	type only: IS1D 00 P21
0x01	Sensor Error X-Axis	type only: IS2D 90 P21
0x02	Sensor Error Y- Axis	type only: IS2D 90 P21
0x80	EEPROM Error: An error occurred while saving the configuration.	
Bit field Communication Errors		
0x01	CAN Warning Limit reached (too many Error Frames)	
0x02	CAN Bus-Off State reached (An Emergency message will be transmitted after the device has recovered from Bus-Off)	
0x04	Receive Queue Overrun,	CAN messages were lost
0x08	Transmit Queue Overrun,	CAN messages were lost
0x80	Guarding Error,	The loss of the Guarding-Master has been detected. (Node Guard Event)

Table 18: Emergency: Manufacturer Specific Error Field

6.9 Failure monitoring

Since the nodes do not respond at regular intervals with the event-controlled transmission in a CANopen network, Heartbeat and Nodeguarding / Lifeguarding failure monitoring mechanisms are provided. Only one of the two monitoring methods can be active.

6.9.1 Nodeguarding / Lifeguarding

Nodeguarding is the monitoring of one or several nodes by the NMT master. The NMT master periodically issues an RTR message frame to the slave to be monitored, which responds with its status and with a toggle bit. If the status or the toggle bit do not comply with the status or toggle bit expected by the guarding master or if no response is provided, the master assumes a slave error.

The node to be monitored can also use this mechanism to detect a failure of the guarding master. To this end, two parameters are used. The interval time after which the guarding master polls the inclination sensor to be monitored is the Guard Time (100Ch). Another parameter, the Life Time Factor (100Dh) defines a multiplier after which the connection is deemed to be interrupted. This time is designated as the node life time.

„Node Life Time“ = „Guard Time“ x „Life Time Factor“

If the inclination sensor does not receive a guarding request from the master within the parametrized time, it also assumes a master failure, sends an emergency message frame and returns to the "Pre-Operational" state. If either of the two parameters is "0" (default setting), the master is not monitored (no Lifeguarding).

6.9.2 Heartbeat

Heartbeat is a failure monitoring mechanism which can operate without using RTR message frames. In this case, the inclination sensor cyclically transmits a heartbeat message which contains the state of the device. The master can monitor these message frames. Heartbeat is activated once a value greater than "0" is entered in the heartbeat interval time register (1017h).

Remarks:
Heartbeat has a significant influence on the bus load of the CANopen network, but produces only half the high bus load of Nodeguarding / Lifeguarding.

6.10 LSS: Layer Setting Service (according to CiA DSP-305)

6.10.1 Setting of Node-ID and Baud Rate

The setting of the node address (Node-ID) and the Baud Rate is realized by the LSS (Layer Setting Service). For communication between LSS Master and LSS Slave (inclination sensor) two CAN identifiers (7E5h and 7E4h) are used. Each inclination sensor has a unique 128-bit LSS address, at which he can be addressed in the CAN network. This address is composed of the three 32-bit parameters of the Identity object 1018h and the serial number:

Vendor-ID	0000 0159h	(Manufacturer ID: GEMAC mbH)
Product Code	0000 5A72h	(5A72h = 23154dec = PR-**23154**-30)
Revision Number	0000 001Eh	(1Eh = 30dec = PR-23154-**30**)
Serial Number	xxxx xxxxh	(respective serial number of the incl. sensor → nameplate)

The default values for Node-ID and Baud Rate at delivery (factory settings) are:

Node-ID	10
Baud Rate	Automatic Baud Rate Detection

Index	Baud Rate
0	1 MBit/s
1	800 kBit/s
2	500 kBit/s
3	250 kBit/s
4	125 kBit/s
5	unused
6	50 kBit/s
7	20 kBit/s
8	10 kBit/s
9	Automatic Baud Rate Detection

Table 19: LSS Baud Rate Index according to CiA DSP-305

6.11 Automatic Baud Rate Detection (according to CiA AN-801)

The automatic baud rate detection is used to automatically adjust the baud rate of the inclination sensor on the existing baud rate in the network. After power-on the inclination sensor only listen to the CAN network without acknowledging the received messages on the bus. This operating condition is characterized by the flickering of the RUN-LED (see also chapter: 6.13„Status LED (according to CiA DR-303-3)“). The sensor checks all the available baud rates. Upon receipt of a valid CAN telegram, the correct baud rate is adjusted. Then he starts up in the mode Pre-Operational using a boot-up message. (see also Figure 8).

Remarks:

For proper operation of the automatic baud rate detection it is necessary to receive messages from other can nodes on the bus.

6.12 Active compensation of thermal accuracy shift

The inclination sensor in metal housing features opposed to the sensor in plastic housing an active compensation of accuracy shift. This is improved by maintaining the sensor element at a constant temperature which is independent of the operation temperature of the inclination sensor.

6.13 Status LED (according to CiA DR-303-3)

The integrated two-color Status LED signals the recent device state (Run LED, green) as well as CAN communication errors that might have occurred (Error LED, red). The color and the flashing frequency of the LED distinguish the different device states as shown below.

Status LED		
RUN LED	**LED State**	**Description**
○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○...	Off	The device is in state Reset or no power supply is connected
☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼...	Flickering	Automatic baud rate detection is currently running (active)
○ ☼ ○ ☼ ○ ☼ ○ ☼ ○ ☼ ○ ☼...	Blinking	The device is in state Pre-Operational
○ ☼ ○ ○ ○ ○ ○ ☼ ○ ○ ○ ○...	Single Flash	The device is in state Stopped
☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼...	On	The device is in state Operational
ERROR LED	**LED State**	**Description**
○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ ○...	Off	The device is in working condition
☼ ○ ○ ○ ○ ○ ☼ ○ ○ ○ ○ ○...	Single Flash	CAN Warning Limit reached
☼ ○ ☼ ○ ○ ○ ○ ○ ☼ ○ ☼ ○...	Double Flash	The loss of the Guarding-Master has been detected. (Node Guard Event)
☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼ ☼...	On	The device is in state Bus-Off

Legend: ○ LED off ☼ LED on ☼ LED flickering (50 ms on/off) Duration of ○/☼: 200 ms

Table 20: Status and Error Display through Two-Color LED

7 Sensor configuration

7.1 Inclination sensor programming adapter

With the optional inclination sensor programming adapter (starter kit) it is possible to adjust all inclination sensors with CAN/CANopen, current or voltage interface. It consists of a programming adapter that is connected via USB to a PC. The connection with the programming adapter is realized through various, also included adapter cables. The inclination sensor is supplied with power through this. An additional power supply is not necessary.

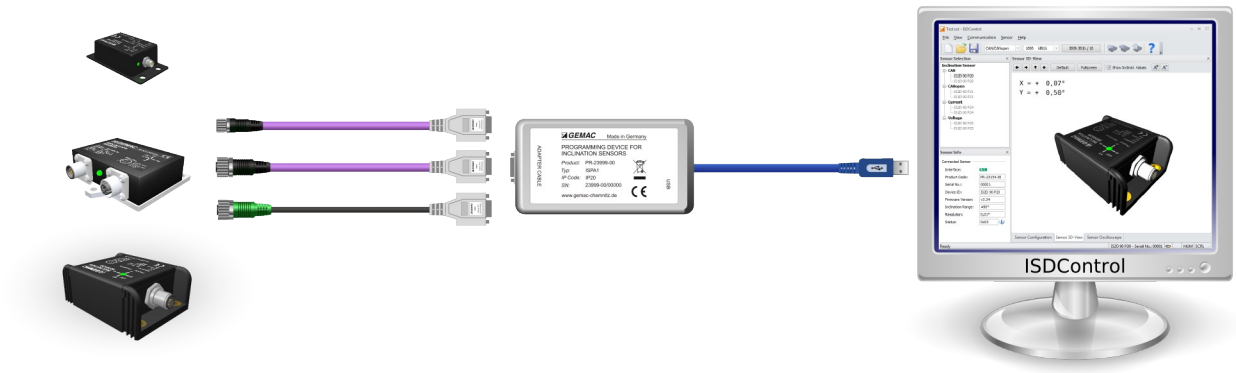


Figure 11: Starter kit

7.2 PC software ISDControl

The parametrization of all possible values is done with the PC software ISDControl, which is included in all starter kits. Each configuration can then be stored in a file.

Features:

- Comfortable configuration of all parameters of the inclination sensor
- 3D imaging and display of the current angle
- Oscilloscope display of the current angle
- Firmware Download option
- Automatic inclination sensor search for unknown communication parameters

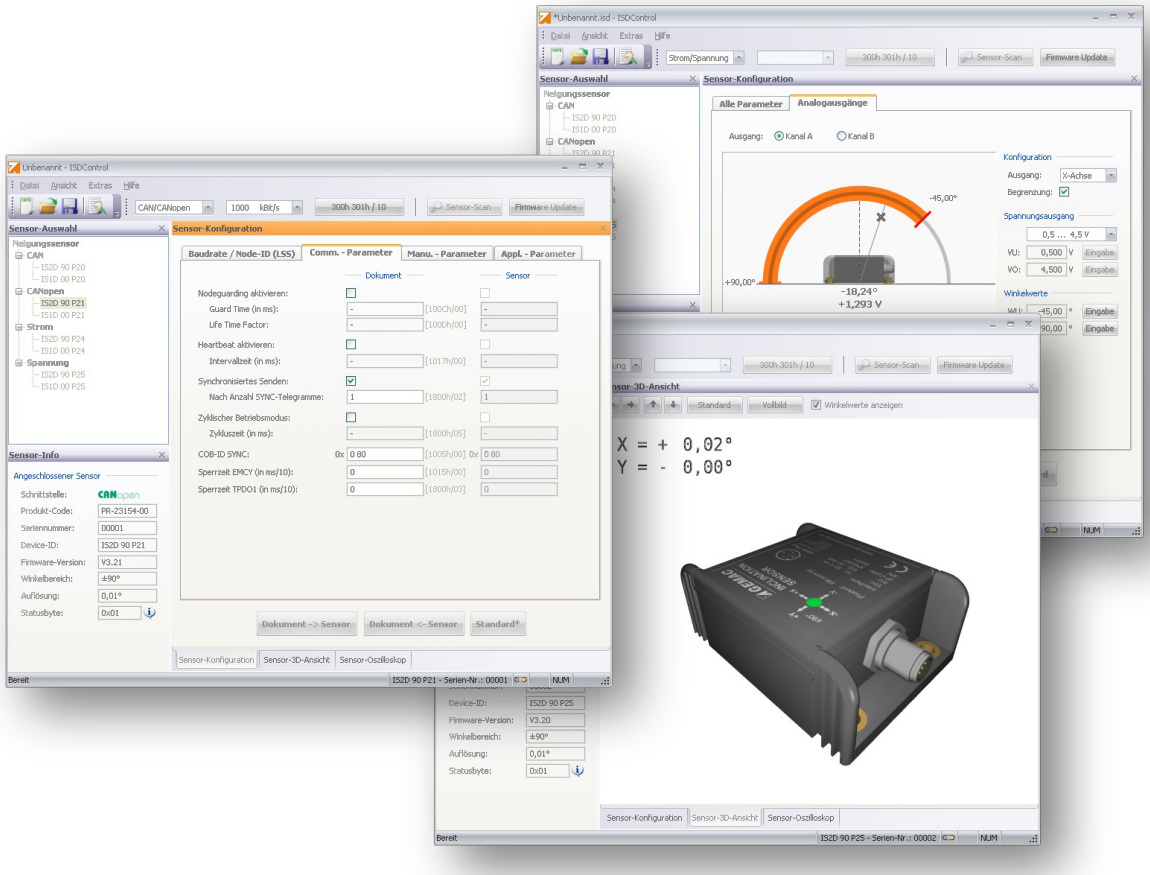


Figure 12: PC software

8 Ordering Information

Article Number	Product Type	Description/Distinction
PR-23150-30	IS1D 00 P21	CANopen, 1-dimensional, 360°, plastic housing
PR-23120-30	IS1D 00 P21	CANopen, 1-dimensional, 360°, metal housing
PR-23154-30	IS2D 90 P21	CANopen, 2-dimensional, ±90°, plastic housing
PR-23124-30	IS2D 90 P21	CANopen, 2-dimensional, ±90°, metal housing
PR-23999-01	ISPA1	Inclination sensor programming adapter (Starter kit including programming adapter, cables and PC software)

Table 21: Ordering Information